

EL465780540
EL355818248

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICATION FOR LETTERS PATENT

* * * * *

Methods For Forming Wordlines, Transistor Gates,
And Conductive Interconnects, And Wordline,
Transistor Gate, And Conductive Interconnect
Structures

* * * * *

INVENTORS

Klaus Florian Schuegraf
Randhir P.S. Thakur

ATTORNEY'S DOCKET NO. MI22-532

1 TECHNICAL FIELD

2 The invention pertains to a number of semiconductor structures
3 and methods for forming such structures, including gate stack structures,
4 conductive line structures, conductive interconnect structures, and
5 programmable-read-only-memory devices.

6

7 BACKGROUND OF THE INVENTION

8 A continuous challenge in semiconductor processing is to improve
9 conductivity and performance of stacked semiconductor structures.
10 Among the stacked semiconductor structures commonly utilized are gate
11 stacks, wordlines, programmable-read-only-memory devices such as
12 EPROMs and EEPROMs, and conductive interconnects. Formation of
13 some of these prior art stacked structures is described with reference to
14 Figs. 1-4. Figs. 1-2 pertain to the formation of a wordline or gate stack
15 structure, and Figs. 3-4 pertain to the formation of a programmable-read-
16 only memory device.

17 Referring to Fig. 1, a semiconductor wafer fragment 10 is
18 illustrated at a preliminary processing step of a prior art process for
19 forming a wordline or gate stack. Wafer fragment 10 comprises a
20 semiconductive material substrate 12, and field oxide regions 14 over
21 substrate 12. A gate dielectric layer 16, generally comprising silicon
22 dioxide, extends between field oxide regions 14. A polysilicon layer 18

1 and a polycide (silicide) layer 20 are formed over field oxide regions 14
2 and gate dielectric layer 16.

3 Polysilicon layer 18 typically comprises polysilicon uniformly doped
4 with a conductivity enhancing dopant (illustrated by stippling within
5 layer 18). Polycide layer 20 comprises a metal silicide, such as tungsten
6 silicide, molybdenum silicide, titanium silicide or cobalt silicide. The
7 formation of polycide layer 20 typically comprises depositing a metal over
8 polysilicon layer 18 and reacting the metal with polysilicon layer 18 to
9 form a metal-silicide. The reacting can comprise thermal processing of
10 the metal layer and polysilicon layer at, for example, temperatures of
11 from about 600°C to about 800°C.

12 Referring to Fig. 2, layers 16, 18 and 20 are patterned to form a
13 conductive stack, and specifically to form a wordline 24. Source/drain
14 regions 25 are provided proximate wordline 24. Conductive wordline 24
15 comprises a transistor gate electrically connecting source/drain regions 25.
16 The final transistor structure can be either a p-channel transistor
17 (PMOS), or an n-channel transistor (NMOS), and can be incorporated
18 within a CMOS construction.

19 The speed of devices comprising wordlines and conductive gates
20 generally increases with increasing conductivities of the wordlines and
21 conductive gates. Accordingly, it would be desirable to improve the
22 conductivity of wordlines and transistor gates. A method for improving
23 the conductivity of a doped layer is to "activate" the dopant within the

1 layer. Although the chemistry of dopant activation is not well
2 understood, activation is thought to occur as dopant is dispersed from
3 grain boundaries in a polysilicon layer to bulk polysilicon away from the
4 grain boundaries. Dopants are typically activated by thermal processing.

5 Alternative procedures similar to those of Figs. 1 and 2 can be
6 used to form a conductive polysilicon interconnect. Such interconnects
7 can comprise a line of polycide over a polysilicon. Accordingly, such
8 interconnects are similar to wordline 24, but lack dielectric layer 16.

9 The speed of devices comprising conductive interconnects can
10 increase with increasing conductivities of the conductive interconnects.
11 Accordingly, it would be desirable to improve the conductivity of
12 conductive interconnects.

13 Referring to Figs. 3-4, a prior art process for forming a
14 programmable-read-only memory (PROM) device is illustrated. In the
15 embodiment of Figs. 3-4, similar numbering to that of the embodiment
16 of Figs. 1-2 is utilized, with differences indicated by the suffix "a", or by
17 different numbers.

18 Referring to Fig. 3, a wafer fragment 10a is illustrated at a
19 preliminary step during formation of a programmable-read-only memory
20 device. Wafer fragment 10a comprises a semiconductive material 12a
21 over which is formed field oxide regions 14a and gate dielectric
22 layer 16a. A first polysilicon layer 18a is formed over regions 14a and
23 dielectric layer 16a. A second dielectric layer 26 and a second

1 polysilicon layer 28 are formed over first polysilicon layer 18a, and a
2 polycide layer 30 is formed over second dielectric layer 26.

3 Polysilicon layers 18a and 28 comprise uniformly doped polysilicon,
4 typically comprising a dopant concentration of greater than
5 1×10^{19} ions/cm³.

6 Referring to Fig. 4, layers 16a, 18a, 20a, 26, 28 and 30 are
7 patterned to form the resulting PROM device 32. Within device 32, the
8 patterned first polysilicon layer 18a is typically referred to as a floating
9 gate. The patterned second polysilicon layer 28 and polycide layer 30
10 together comprise a conductive line 33.

11 The speed of circuits comprising PROM devices can increase with
12 increasing conductivities of the conductive line and floating gate.
13 Accordingly, it would be desirable to improve the conductivities of
14 conductive lines and floating gates.

1 **SUMMARY OF THE INVENTION**

2 The invention encompasses stacked semiconductor devices including
3 gate stacks, wordlines, PROMs, conductive interconnecting lines, and
4 methods for forming such structures.

5 In one aspect, the invention includes a method of forming a
6 conductive line. A silicide layer is formed against a polysilicon layer.
7 A conductivity-enhancing impurity is provided within the silicide layer.
8 The polysilicon layer and the silicide layer are formed into a conductive
9 line shape.

10 In another aspect, the invention includes a programmable-read-only-
11 memory device comprising a first dielectric layer over a substrate, a
12 floating gate over the first dielectric layer, a second dielectric layer over
13 the floating gate, a conductive line over the second dielectric layer, and
14 a metal-silicide layer over the conductive line. The metal-silicide layer
15 comprises a Group III dopant or a Group V dopant.

16

17 **BRIEF DESCRIPTION OF THE DRAWINGS**

18 Preferred embodiments of the invention are described below with
19 reference to the following accompanying drawings.

20 Fig. 1 illustrates a semiconductor wafer fragment at preliminary
21 step of a prior art method for forming a wordline.

22 Fig. 2 illustrates the Fig. 1 wafer fragment at a prior art step
23 subsequent to that of Fig. 1.

1 Fig. 3 illustrates a semiconductor wafer fragment at preliminary
2 step of a prior art method for forming PROM device.

3 Fig. 4 illustrates the Fig. 3 wafer fragment at a prior art step
4 subsequent to that of Fig. 3.

5 Fig. 5 illustrates a semiconductor wafer fragment at preliminary
6 step of a first embodiment method of the present invention for forming
7 a wordline.

8 Fig. 6 illustrates the Fig. 5 wafer fragment at a step subsequent
9 to that of Fig. 5.

10
11
12
13
14
15
16
17
18
19
20
21
22
23

1 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

2 This disclosure of the invention is submitted in furtherance of the
3 constitutional purposes of the U.S. Patent Laws "to promote the progress
4 of science and useful arts" (Article 1, Section 8).

5 A first embodiment of the present invention is described with
6 reference to Figs. 5 and 6. In describing the first embodiment, like
7 numerals from the preceding discussion of the prior art are utilized
8 where appropriate, with differences being indicated by the suffix "b" or
9 with different numerals.

10 Referring to Fig. 5, a semiconductor wafer fragment 10b is
11 illustrated at a preliminary processing step. Wafer fragment 10b
12 comprises a semiconductive material substrate 12b, such as, for example,
13 monocrystalline silicon. Field isolation regions 14b and a gate dielectric
14 layer 16b are formed over semiconductive material 12b. Field isolation
15 regions 14b and gate dielectric layer 16b comprise an insulative material,
16 such as, for example, silicon dioxide.

17 A conductive layer 18b and a polycide layer 20b are formed over
18 field isolation regions 14b and gate dielectric layer 16b. Conductive
19 layer 18b preferably comprises polysilicon doped to a concentration of
20 greater than 1×10^{19} atoms/cm³ with a conductivity enhancing dopant.
21 Polycide layer 20b is against conductive layer 18b and comprises a metal
22 silicide doped with conductivity enhancing dopant (the dopant being
23 indicated by stippling). Preferably, polycide layer 20b is doped to a

1 concentration of greater than 1×10^{18} atom/cm³ with the conductivity
2 enhancing dopant.

3 Polycide layer 20b can comprise, for example, a metal selected
4 from the group consisting of tungsten, tantalum, titanium, molybdenum
5 and cobalt. Polycide layer 20b can be formed by the prior art method
6 of depositing a metal over polysilicon layer 18b and reacting the metal
7 with polysilicon layer 18b at temperatures of from about 600°C to about
8 800°C to form silicide layer 20b. Alternatively, and preferably, the
9 thermal processing to form polycide layer 20b encompasses rapid thermal
10 processing (RTP). In the context of this document, RTP refers to a
11 process wherein a temperature is ramped at greater than about
12 7°C/second. Preferably, the RTP temperature is ramped to exceed 850°C
13 and is maintained above 850°C for at least 10 seconds. Such RTP can
14 activate dopant within polycide layer 20b to increase the conductivity of
15 doped polycide layer 20b.

16 The RTP preferably occurs while exposing silicide layer 20b to an
17 oxygen-comprising atmosphere, such as, for example, an atmosphere
18 comprising at least one compound selected from the group consisting of
19 O₂, O₃, N₂O and NO. Under such preferred conditions, a silicon dioxide
20 layer 35 can be formed over polycide layer 20b. Silicon dioxide layer 35
21 can impede or prevent dopant diffusion outwardly from layer 20b and
22 thereby advantageously retain dopant within layer 20b. It is noted that
23 while the RTP preferably occurs while exposing layer 20b to an oxidizing

1 atmosphere, the RTP will generally also activate dopant within layer 20b
2 if conducted while exposing layer 20b to a non-oxidizing atmosphere.

3 Wafer 10b differs from wafer 10 of the prior art (shown in Figs. 1
4 and 2) in that polycide layer 20b is doped with a conductivity-enhancing
5 impurity, whereas the prior art polycide 20 (shown in Figs. 1 and 2) is
6 not doped. As indicated above, the conductivity-enhancing dopant is
7 preferably provided to a concentration of greater than 1×10^{18} atom/cm³.
8 Suitable conductivity enhancing dopants can comprise, for example, Group
9 III or Group V dopants, such as dopants comprising boron, phosphorous
10 or arsenic. Methods for doping silicide layer 20b include, for example,
11 implanting dopant into the layer after formation/deposition of the layer,
12 *in situ* doping of the layer during either chemical vapor deposition
13 (CVD) or sputter deposition, and out-diffusion from a doped polysilicon
14 layer 18b beneath silicide layer 20b.

15 An example CVD process for forming a polycide layer 20b
16 comprising tungsten silicide doped with phosphorus (WSi_xP_y) comprises
17 utilization of WF_6 , SiH_4 and PH_3 as precursor materials in a CVD
18 reactor. Alternatively, dichlorosilane can be substituted for SiH_4 . Also,
19 alternative dopant hydrides can be substituted for PH_3 to form a polycide
20 doped with an alternative dopant. Such alternative metal hydrides can
21 include, for example, AsH_3 or diborane. Also, other organic precursors
22 comprising Group III or Group V dopants can utilized as alternative
23 sources of dopant.

1 An example sputter deposition process comprises utilization of a
2 target comprising a mixture of a source of metal, a source of silicon and
3 a source of conductivity-enhancing impurity. The target is sputtered to
4 form a silicide layer 20b comprising the conductivity-enhancing impurity
5 and the metal.

6 Referring to Fig. 6, layers 16b, 18b, 20b, and 35 are patterned to
7 form a conductive line 24b. Source/drain regions 25b are formed within
8 substrate 12b such that conductive line 24b comprises a stacked transistor
9 gate structure which electrically connects source/drain regions 25b. The
10 resulting transistor structure can be a PMOS transistor or NMOS
11 transistor, and can be incorporated into a CMOS structure.

12 Conductive line 24b differs from conductive line 24 (shown in
13 Fig. 2) in that line 24b comprises a silicide layer 20b doped with
14 conductivity-enhancing impurity. Such doping of layer 20b can lower the
15 resistance of layer 20b relative to that of layer 20 (shown in Fig. 1) and
16 thereby improve the performance of conductive line 24b relative to that
17 of conductive line 24 (shown in Fig. 2). The above-discussed RTP can
18 further improve the conductivity of layer 20b by activating dopant within
19 layer 20b.

20 Although layer 20b is doped prior to patterning of layer 20b to
21 form wordline 24b in the shown method, in alternative embodiments layer
22 20b can be doped after such patterning. As an example method of
23 accomplishing such alternative embodiments, layer 20b could be doped by

1 ion implanting a conductivity enhancing dopant into layer 20b after
2 patterning of layer 20b to form wordline 24b. As another example
3 method, layer 20b can be doped by out-diffusion from conductively doped
4 layer 18b by thermal treatment of wordline 24b.

5 The doped silicide of the present invention can be incorporated
6 into numerous circuit device structures, including, for example,
7 programmable-read-only-devices such as EPROMS and EEPROMS.

8 To aid in interpretation of the claims that follow, the term
9 "semiconductive substrate" is defined to mean any construction comprising
10 semiconductive material, including, but not limited to, bulk
11 semiconductive materials such as a semiconductive wafer (either alone or
12 in assemblies comprising other materials thereon), and semiconductive
13 material layers (either alone or in assemblies comprising other materials).
14 The term "substrate" refers to any supporting structure, including, but not
15 limited to, the semiconductive substrates described above.

16 In compliance with the statute, the invention has been described
17 in language more or less specific as to structural and methodical
18 features. It is to be understood, however, that the invention is not
19 limited to the specific features shown and described, since the means
20 herein disclosed comprise preferred forms of putting the invention into
21 effect. The invention is, therefore, claimed in any of its forms or
22 modifications within the proper scope of the appended claims
23 appropriately interpreted in accordance with the doctrine of equivalents.